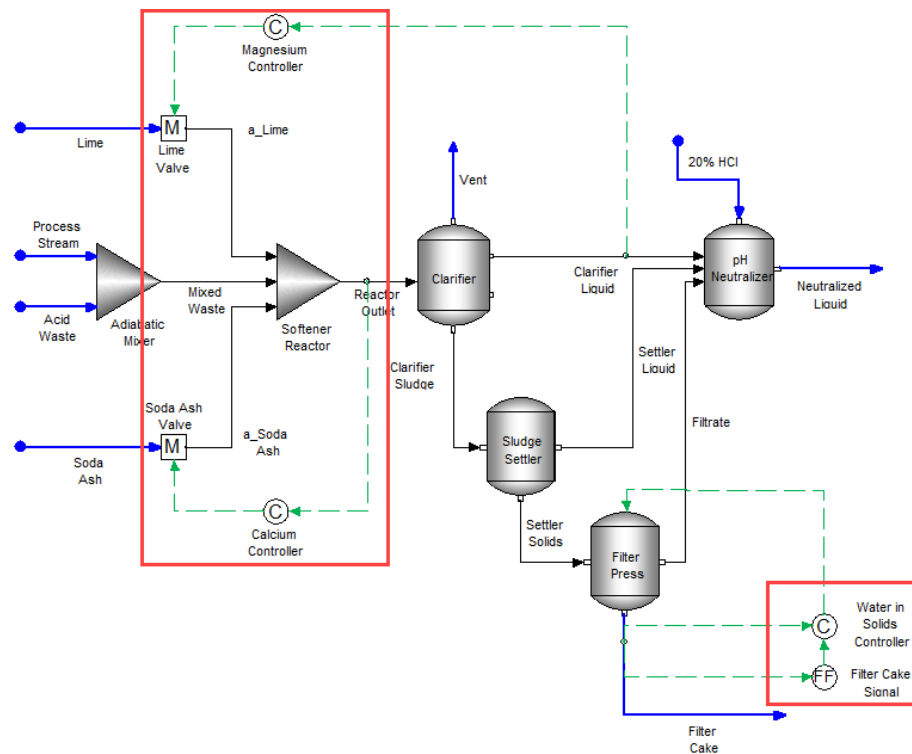


# Chapter 7 Water Treatment – Adding Manipulators and Controllers

## The Application

This chapter introduces the controller objects that enable users to meet target specifications without requiring the user to manually adjust a concentration, flowrate, or conditions. There are three targets in this process: Clarifier Liquid pH, Clarifier Liquid calcium, and Filter Cake water.

## Formulating the Process



Softening and Neutralization Process

You are continuing with the process created in Chapter 06. If you have not completed this section, then return to the previous Chapter.

Total hardness,  $\text{Ca}^{+2}$  &  $\text{Mg}^{+2}$ , is removed using soda ash and lime. The exact amount of each used was fixed at specific values that seemed to produce good results. In this chapter you will set a target concentration for total dissolved  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$ , and adjust the **soda ash** and **lime** automatically. This is done using the Manipulator and Feedback Controller. Then, you will use Feedforward and Feedback controllers to specify the water content in the filter cake.

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## Chemistry Model

### *Opening an existing Case file*

Open the case created in Chapter 6. Water Treatment – Lime Softener.

There is no chemistry change in this step.

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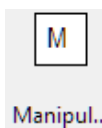
## Building the Process

### Adjusting the Front-end of the Process

The first step is to insert “valves” to the lime and soda ash streams. A valve is simulated using a Manipulate block. The manipulate block receives information from the control block and adjusts the inflow rate accordingly.

#### *Adding the Manipulate block*

- ✓ Select the **Manipulate** object in the **Library** and drag it adjacent to the **Lime** stream.



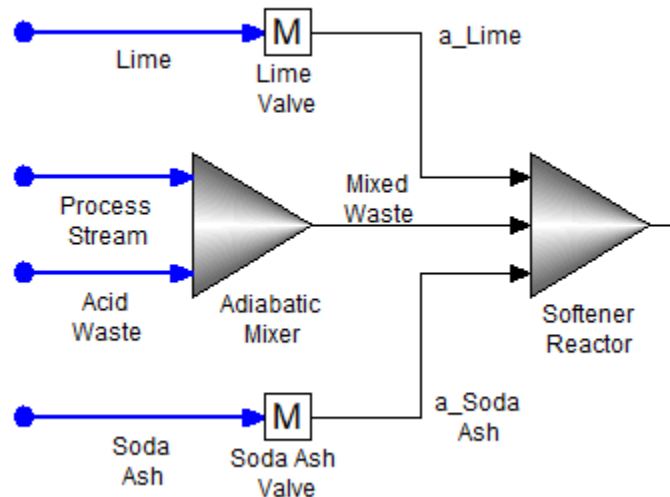
*The manipulate object*

- ✓ Label it **Lime Valve**.
- ✓ Select another **Manipulate** object and drag it adjacent to the **soda ash** stream.
- ✓ Label it **Soda Ash Valve**.
- ✓ Disconnect the **Lime** stream from the **Softener Reactor** block and attach it to the **Lime Valve**.
- ✓ Disconnect the **Soda Ash** stream and attach it to the **Soda Ash Valve**.

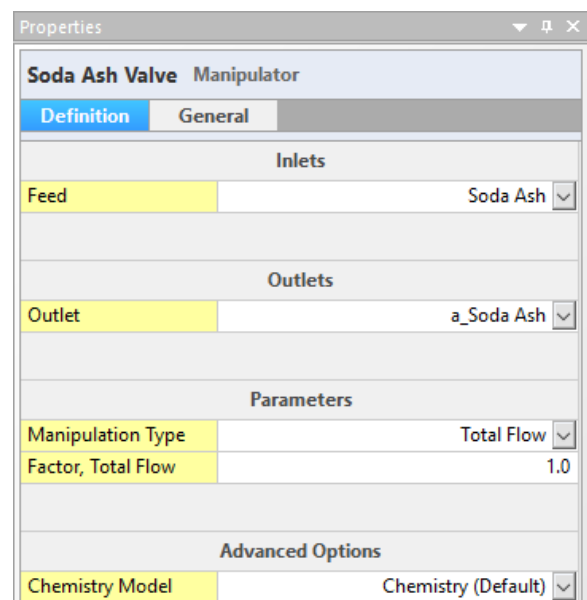
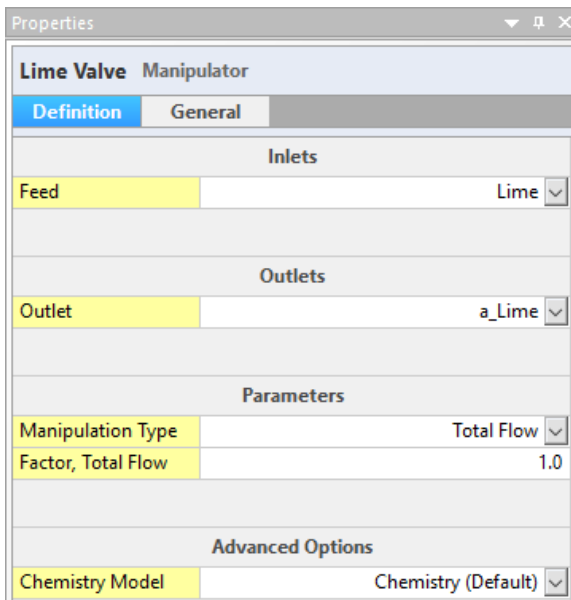
At this point, you may want to reorganize the streams and blocks to make them easier to view on the page.

- ✓ Add a stream between the **Lime valve** and the **Softener Reactor**. Label it “a\_Lime” that stands for adjusted Lime.
- ✓ Add a stream between the **Soda Ash valve** and the **Softener Reactor**. Label it “a\_Soda Ash”

The new connections should look like the image below



- ✓ Click on the **Lime** or **Soda Ash valve** to view the **Factor Flow** in the **Properties** panel.



The Properties panel for the Manipulate object

The factor flows for each valve is set to 1.0 by default. Thus 100% of the inflow stream is sent to the Softener Reactor.

- ✓ Calculate.

The results are identical to the previous run. The Manipulate block multiplies the flow rate of the stream by this factor flow value. When the controller is linked to the Manipulator, it will adjust this factor flow value until the target dissolved calcium and magnesium concentrations are met.

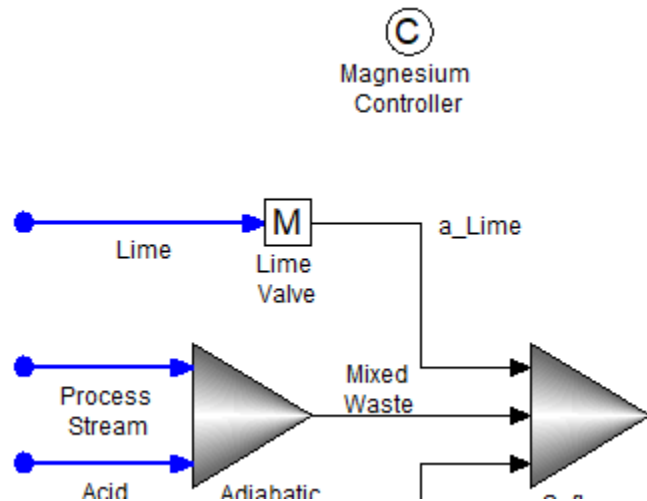
### **Adding the Magnesium Controller**

This Magnesium Controller block measures the dissolved magnesium concentration, compare it to the target magnesium concentration, and adjust the lime flow rate (via the factor flow value) until this value is obtained. Controller require several iterations to converge, since it is searching for the Factor, Flow value that will produce the target concentration.

- ✓ Click on the **Feedback Controller** object in the **Library** and drag it above-right of the **Lime Valve**.



- ✓ Label it **"Magnesium Controller"**.

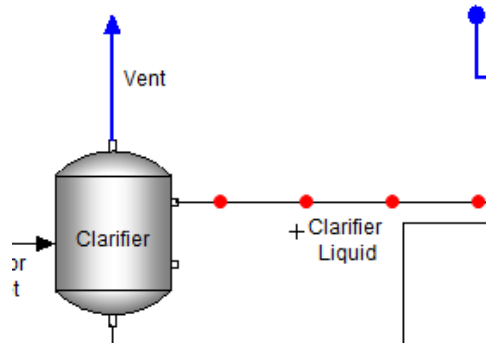


- ✓ Click on the **Add Controller Connection** button in the toolbar.

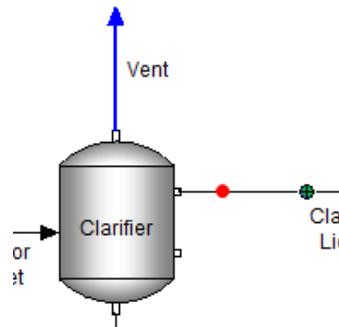


*The Controller Connection button in the toolbar. It links controllers to streams and objects*

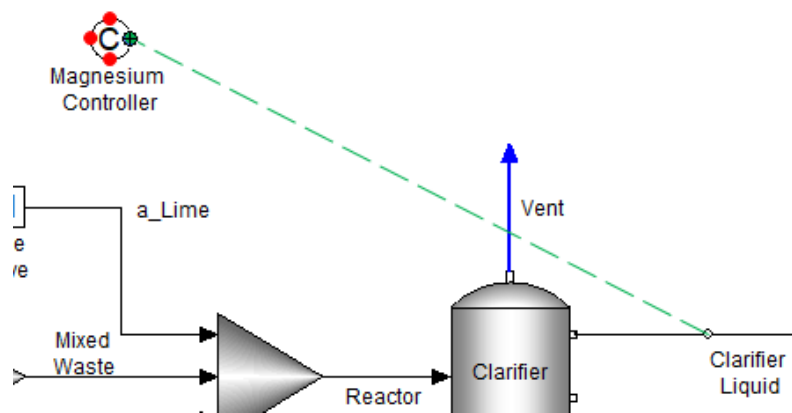
- ✓ Mouse over the **Clarifier Liquid** stream. Red dots appear on the stream.



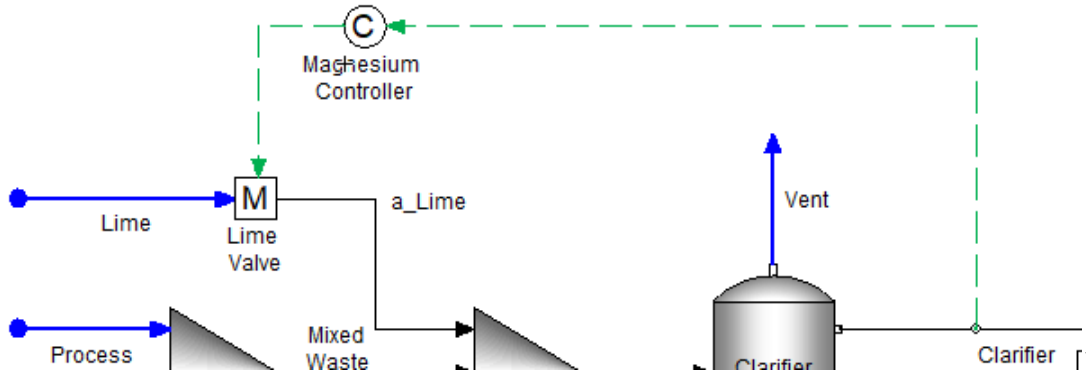
- ✓ Click on one of the red dots to link the signal line to the stream. The dot will turn green when you are ready to click on it to do the connection.



- ✓ Then, mouse over the right edge of the **Magnesium controller** until red dots appear.
- ✓ Click on one of them to link the other side of the signal stream.



- ✓ Next, link the **Magnesium controller** to the **Lime Valve** using a second signal stream.

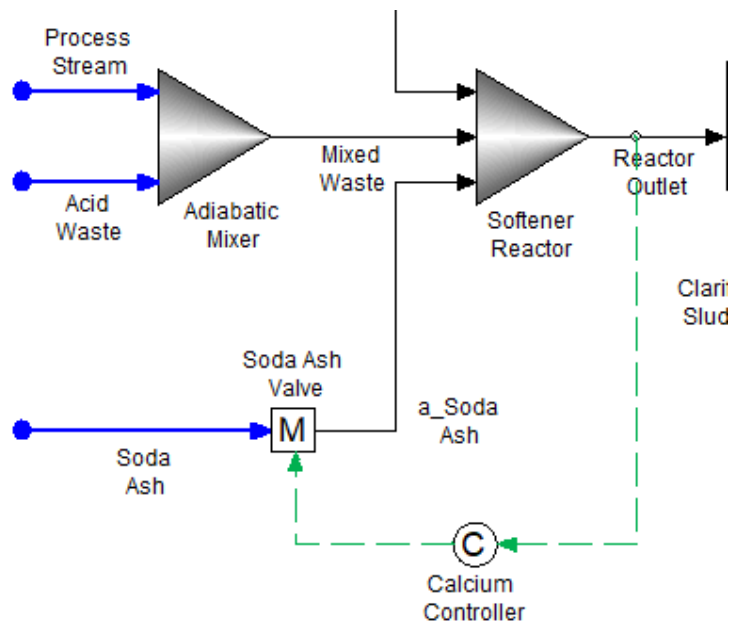


The Feedback Controller is linked to the process stream and to the manipulate block

### Adding the Calcium Controller

You will repeat the steps taken for the Magnesium controller with the Calcium controller. The calcium controller compares the dissolved calcium concentration to the target specification and adjusts the soda ash valve Factor flow.

- ✓ Select the **Feedback Controller** again and drag it below-right of the **Soda Ash valve**. Label it **“Calcium Control”**.
- ✓ Click on the **Add Controller Connection** button in the toolbar.
- ✓ Link the **Reactor Outlet** stream to the **Calcium Controller** block.
- ✓ Link the **Calcium controller** to the **Soda Ash Valve**.

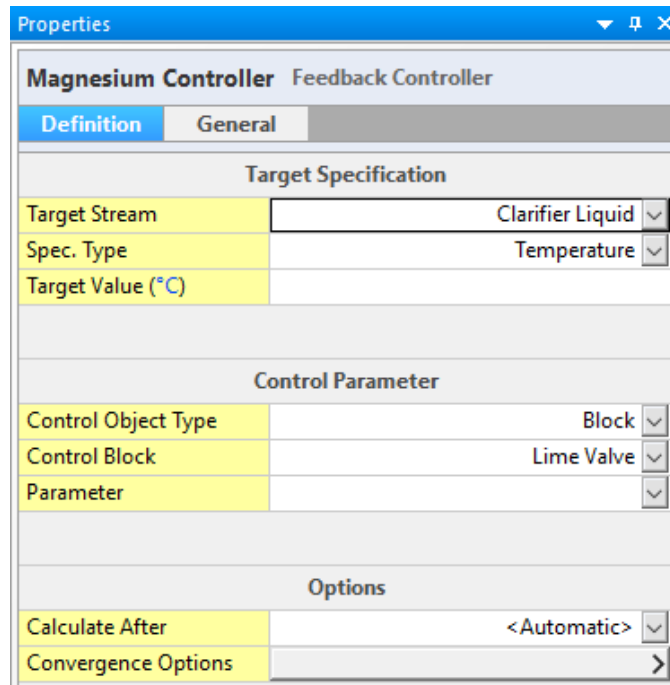


The Calcium Feedback Controller linked to the soda ash valve

## Specifying the Magnesium Controller

- ✓ Click on the **Magnesium Controller** to access the **Properties** panel.

The main panel contains three sections: **Target Specifications**, **Control Parameters**, and **Options**. A fourth section, **Convergence Option**, is on a separate page because it contains multiple settings.



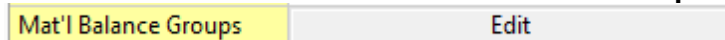
*The Magnesium Feedback Controller Panel*

The **Target Specification** section instructs the controller to measure one of several variables: temperature, pressure, phase flow rates, concentrations, component flow rates and among others. The **Control Parameter** section adjust a variable until the measured value meets the target value.

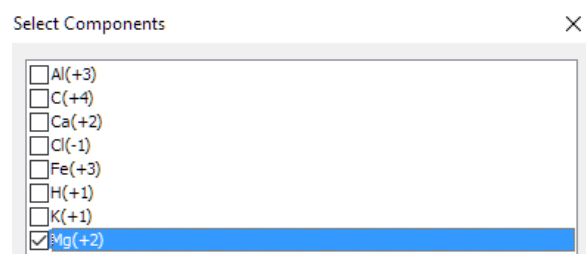
- ✓ Change the **Spec. Type** from the default **Temperature** to **Mat'l balance Group Composition**.



- ✓ Click on the **Edit** button on the **Mat'l Balance Groups** row.



- ✓ Check the box for Mg(+2) and press **OK** close the window.



*Selecting the Mg+2 material balance group in the controller*

- ✓ Click on the **Basis** cell and select **Concentration**.

Basis	Concentration
-------	---------------

- ✓ Click on the **Phase** cell and select **Aqueous Only**.

Phase	Aqueous Only
-------	--------------

- ✓ Enter a Target value of 5 mg/L.

Target Value (mg/L)	5.0
---------------------	-----

- ✓ Click on the **Control Object Type** in the **Control Parameter** section and select **Block**

Control Object Type	Block
---------------------	-------

- ✓ Click on **Control Block** and select **Lime Valve**

Control Block	Lime Valve
---------------	------------

- ✓ Click on **Parameter** and select Factor, Total Flow.

Parameter	Factor, Total Flow
-----------	--------------------

The panel should look like this when done.

Magnesium Controller Feedback Controller	
Definition General	
Target Specification	
Target Stream	Clarifier Liquid
Spec. Type	Mat'l Balance Group Composition
Basis	Concentration
Phase	Aqueous Only
Mat'l Balance Groups	Edit
Target Value (mg/L)	5.0
Control Parameter	
Control Object Type	Block
Control Block	Lime Valve
Parameter	Factor, Total Flow

*The completed Magnesium Feedback Controller Panel*

### **Specifying the Calcium Control controller**

- ✓ Select the **Calcium Controller** object to access the **Properties** panel.

- ✓ Change the **Spec Type** in the **Properties** panel to **Mat'l Balance Group Composition**.

Spec. Type	Mat'l Balance Group Composition
------------	---------------------------------

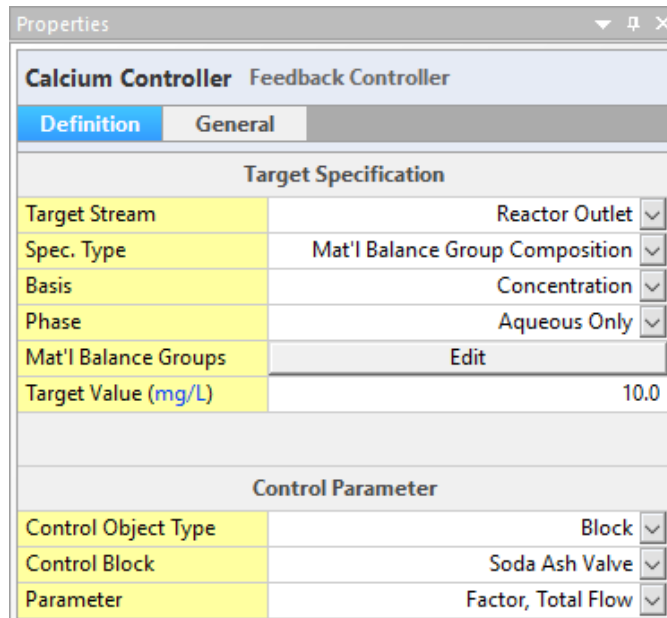
- ✓ Open the **Edit** button on the **Mat'l Balance Groups** row and select Ca(+2).





- ✓ Change the **Basis** to **Concentration**. Basis Concentration ▼
- ✓ Change the **Phase** to **Aqueous Only**. Phase Aqueous Only ▼
- ✓ Change the **Target Value** to 10 mg/l. Target Value (mg/L) 10.0
- ✓ Click on the **Control Object Type** in the **Control Parameter** section and select **Block**. Control Object Type Block ▼
- ✓ Click on **Control Block** and select **Soda Ash Valve**. Control Block Soda Ash Valve ▼
- ✓ Click on **Parameter** and select Factor, Total Flow. Parameter Factor, Total Flow ▼

Your Calcium Controller Parameters panel should look like this:



*The completed Calcium Feedback Controller Panel*

### Reviewing the Controller results

- ✓ **Save** the changes
- ✓ **Run** the case

- ✓ When completed, click on the **Lime Valve** and select the **Watch** tab at the base of the panel.
- ✓ Look at the **Factor, Total Flow** value.

The software multiplied the **Lime** Stream flow rate by 1.017. The Lime flow is 80 mol/hr. Therefore, the actual flow is 81.37 mol/hr. This can be confirmed by reviewing the **a\_Lime** flow rate.

- ✓ Click on the **a\_Lime** stream and review the **Moles, True** row in the **Properties** Panel.

Moles, True (mol/hr)	81.3706
----------------------	---------

Next, you will confirm that the magnesium concentration is 5 mg/l. You will look for this in the Report section.

- ✓ Click on the **Report-1** tab.
- ✓ Change one of the columns to **Clarifier Liquid**.
- ✓ Scroll down to the **MBG Totals, Liquid-1** section (near the bottom of the report).

- ✓ Click on the mol/hr units. 

MBG Totals, Liquid-1 (mol/hr)
-------------------------------

- ✓ Change the Aqueous Composition Basis from moles to concentration.

Output variables	
Aqueous Composition	Concentration mg/L

- ✓ Close the Units Manager window. Find the Mg(+2) concentration– it should be 5 mg/L.

Mg(+2)	5.0
--------	-----

- ✓ Review the calcium concentration – it should be 10 mg/L.

Ca(+2)	10.0
--------	------

- ✓ Next change the stream columns in the Report to show **a\_Lime** and **a\_Soda Ash**.
- ✓ Scroll to the top of the table and view the **Stream Parameters** section.

The target Mg<sup>+2</sup> and Ca<sup>+2</sup> concentrations exiting the Reactor are achieved. The controllers computed that 81.4 mol/hr lime and 109.9 moles soda ash were required. Our initial inputs of 80 and 115 were good, but the controller optimized it within seconds.

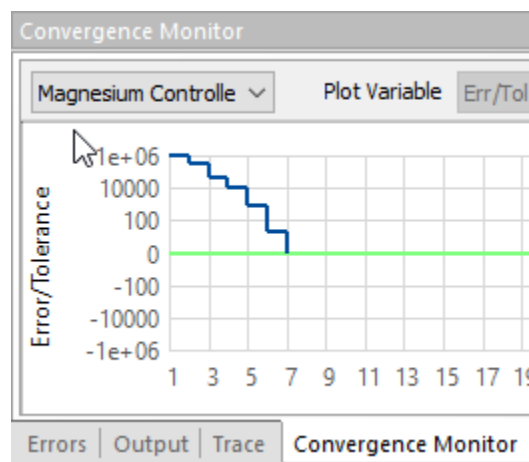
**PLEASE NOTE.** The Calcium Controller and Magnesium Controller connections were on different streams. Calcium Controller measured the Reactor Outlet, and the Magnesium Controller measured the Clarifier Liquid. Ideally, both would be on the same stream, but this sometimes causes convergence problems, and so keeping them separate generally speeds up the calculation.

The purpose of this example is to illustrate how the controller works with the multiplier and target stream to achieve the desired value. The number of iterations/passes, that the controller required to meet the specification can be observed in the **Convergence Monitor**.

### Using the convergence monitor

The Panel at the bottom of the software contains several tabs, including **Output**, **Errors**, **Trace**, and **Convergence Monitor**. The **Convergence Monitor** tab is a graphic representation of the progress for controllers and recycle streams.

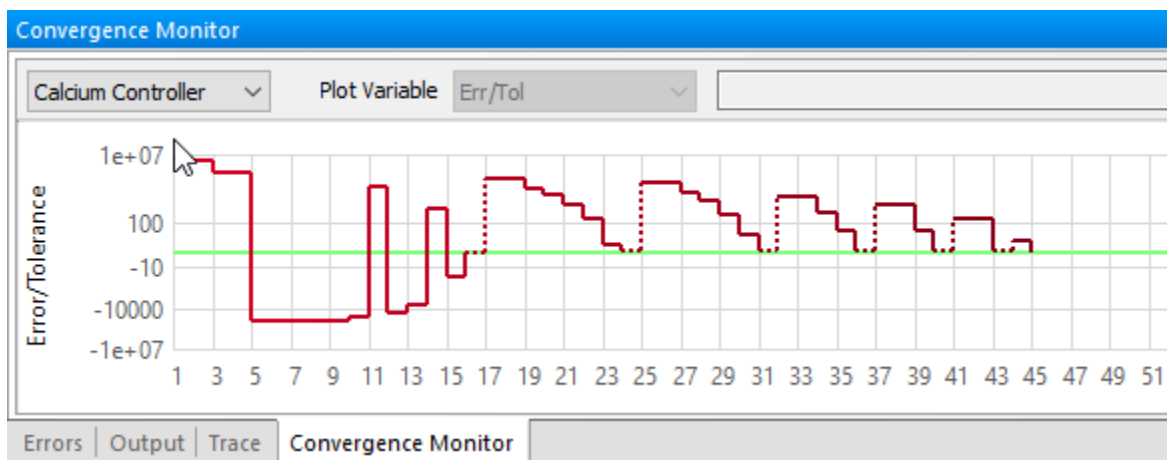
- ✓ Click on the **Convergence Monitor** tab.
- ✓ The default variable view is **<Automatic>**
- ✓ Click on the **Automatic** button and select **Magnesium Controller**.
- ✓ It took seven iterations for the Magnesium controller to achieve its target specification.



*The Convergence monitor output for the magnesium controller*

- ✓ Change the view from Magnesium to **Calcium controller**

By comparison, the calcium controller took about forty five iterations to converge on the right concentration.



*The Convergence monitor output for the calcium controller*

## Updating the controller settings

It is possible to start subsequent calculations at this converged point. There is a tool called **Restart Options** that updates a number of converged settings, including controllers. It is also relatively easy to access.

- ✓ Click anywhere on the flowsheet, so that nothing is selected. This causes the Flowsheet Properties to appear in the Specifications panel. (when no stream or unit is selected, the Flowsheet Properties is the panel's focus)

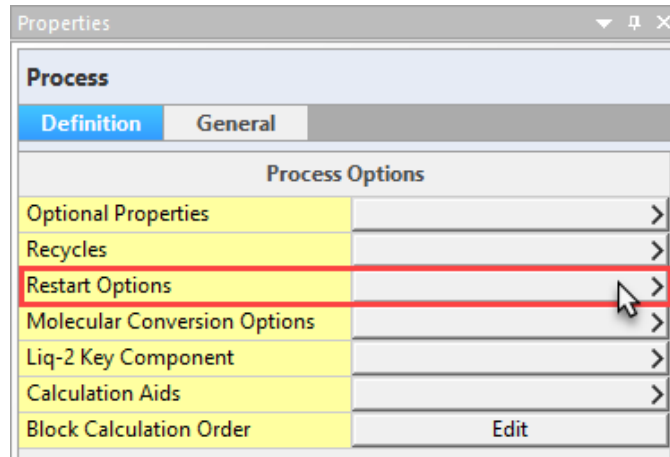
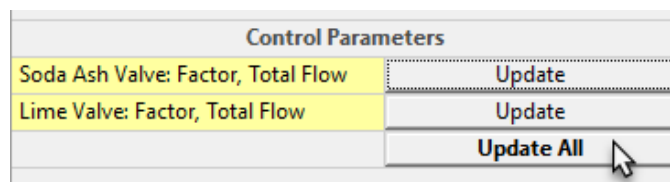
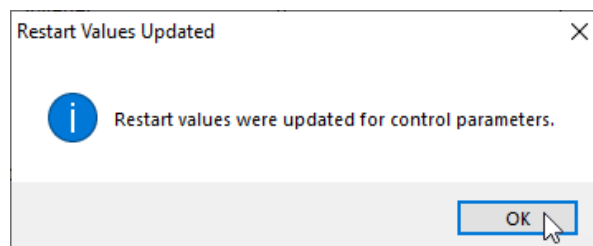


Figure 7-1 – The Flowsheet (Process) options panel

- ✓ Click on the **Restart Options** button
- ✓ Click on the **Update All** button in the **Control Parameters** section



A window appears stating that settings for some objects were updated.



- ✓ Press **OK** and **Calculate** again.
- ✓ View the **Convergence Monitor**.

The monitor should now be empty because the controllers converged in the first iteration.

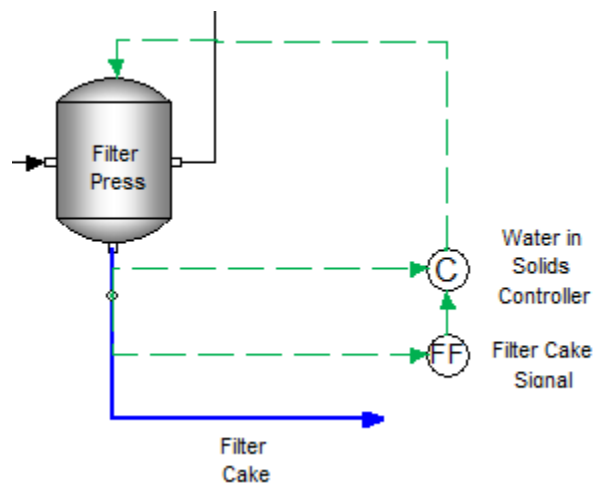
- ✓ Save your file.

### **Setting the Water content in the filter cake**

The water content in the filter cake is currently based on split values entered in the filter block settings. These are fixed/static values, that will not vary, even if the water inflows or controllers are varied. They are, therefore, not a function of the filter press efficiency. Controllers can be used to create more robust specifications.

In this case, the controller reads the solids mass in the filter cake and adjusts the water mass so that a target fraction is achieved. A water content of 9 mass% for example would be reasonable. Thus, the water to solids ratio would be 1:10.

Adding this setting requires two controllers, a feedback controller (FB) to adjust the water flow rate, and a feed forward (FF) controller that tells the feedback (FB) controller how much solids are being produced. The image below illustrates how these objects should look when you are done.



*The filter press linked to a Feed Forward and Feedback controller so that the water content in the filter cake is fixed at 9%.*

### **Add the objects**

- ✓ Click on the **FF Controller** object in the **Library** and drag it to the lower right of the **Filter press**.
- ✓ Label the (FF) Feed-fwd controller, **Filter Cake Signal**.
- ✓ Click on the (FB) Feedback Controller object and drag it above the FF controller.
- ✓ Label the FB controller **Water in Solids Controller**.

### **Link the signals to the objects**

- ✓ Next, click on the **Add Controller Connection** button in the toolbar – you will add four connections.
- ✓ Link the **Filter cake** stream to the **FF controller** (Filter Cake Signal).

- ✓ Link the **FF Controller** to the **FB Controller** (Water in solids controller).
- ✓ Link the **Filter Cake** to the **Feedback controller** (there are two signal lines from the filter cake).
- ✓ Link the **Feedback controller** to the **Filter Press** (block).

This is how the four signal lines and the controllers operate:

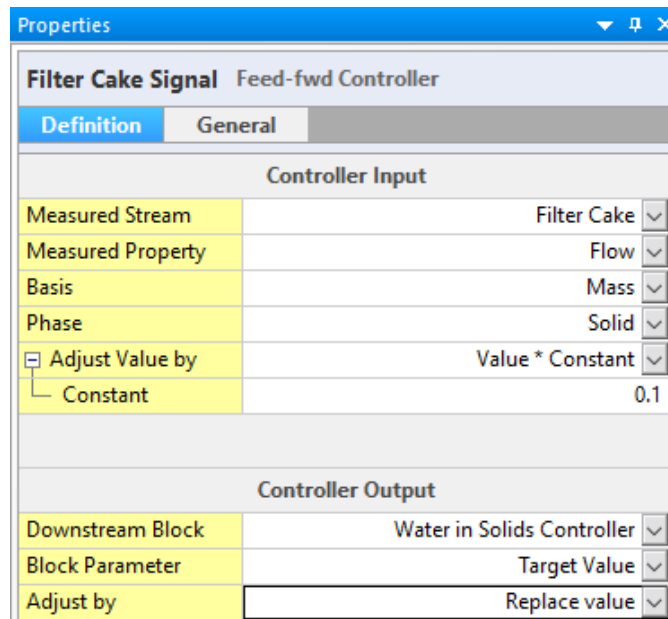
- The first signal line (Filter Cake stream to Filter Cake Signal controller) sends to the FF controller the current solids flow rate (kg/hr).
- The second signal line (Filter Cake Signal controller to Water in Solids controller) sends the FB controller how much liquid mass needs to be in the Filter cake stream ( $0.1 \times \text{solids flow rate}$ , kg/hr).
- The third signal line (Filter Cake stream to Water in Solids controller) sends to the FB controller the current liquid mass in the cake (kg/hr).
- The fourth signal line (Water in Solids Controller to Filter Press) instructs the filter press to change the water flow fraction to the Filter Cake stream so as to achieve the proper water mass in the filter cake.

### ***Assigning Settings to the Feed Forward controller***

You will adjust the properties panel for this controller.

- ✓ Click on the FF controller, now called **Filter Cake Signal**.
- ✓ The **Measured stream** should be **Filter Cake**. If not change it.
- ✓ Change the **Controller Input** settings to the following:
  - Measured Property = Flow
  - Basis = Mass
  - Phase = Solid
  - Adjust Value by = Value \* Constant
  - Constant = 0.1
- ✓ Change the Controller Output settings to the following:
  - Downstream Block = Water in Solids controller
  - Block Parameter = Target Value
  - Adjusted by = Replace Value

When completed, it should look like this:



*The completed Properties panel for the Filter Cake signal*

You have instructed the FF controller to do the following: Measure the solid mass flow rate in the filter cake. This mass is multiplied by 0.1 and that value is sent to the Feedback controller. In this case, there is 15.45 kg/hr of solids exiting the Filter press. The FF controller will send a 1.545 kg/hr value to the Feedback controller.

### **Assigning settings to the Feedback controller**

The feedback controller will measure the filter cake liquid flow rate, and adjust the “Liquid in Solid” split so that 1.545 kg/hr liquid exits with the filter cake.

- ✓ Click on the **Water in Solids controller**.
- ✓ The Target stream should be Filter Cake – if not change it.
- ✓ Change the settings to the following:
  - Spec Type = Flow
  - Basis = Mass
  - Phase = Aqueous Only
  - Target Value = 1000 (g/hr)
  - Control Object Type = Block
  - Control Block = Filter Press

- Block Parameters = Liq. in Solid Stream

This is how the feedback controller will look when you have completed the following steps.

Water in Solids Controller Feedback Controller	
Definition	General
Target Specification	
Target Stream	Filter Cake ▾
Spec. Type	Flow ▾
Basis	Mass ▾
Phase	Aqueous Only ▾
Target Value (g/hr)	1000.0
Control Parameter	
Control Object Type	Block ▾
Control Block	Filter Press ▾
Parameter	Liq. in Solids Stream ▾

The completed Properties panel for the Water in Solids controller

### Setting the calculation order so that the Feed Forward controller calculates before the Feedback controller

The last step is to instruct the software to calculate the FF controller before the FB controller. This is because the FF needs to send the required liquid mass to the FB controller before the FB controller is calculated.

- ✓ Click anywhere on the white section of the Flowsheet (to activate the Process properties).
- ✓ Click on the Block Calculation Order Edit button

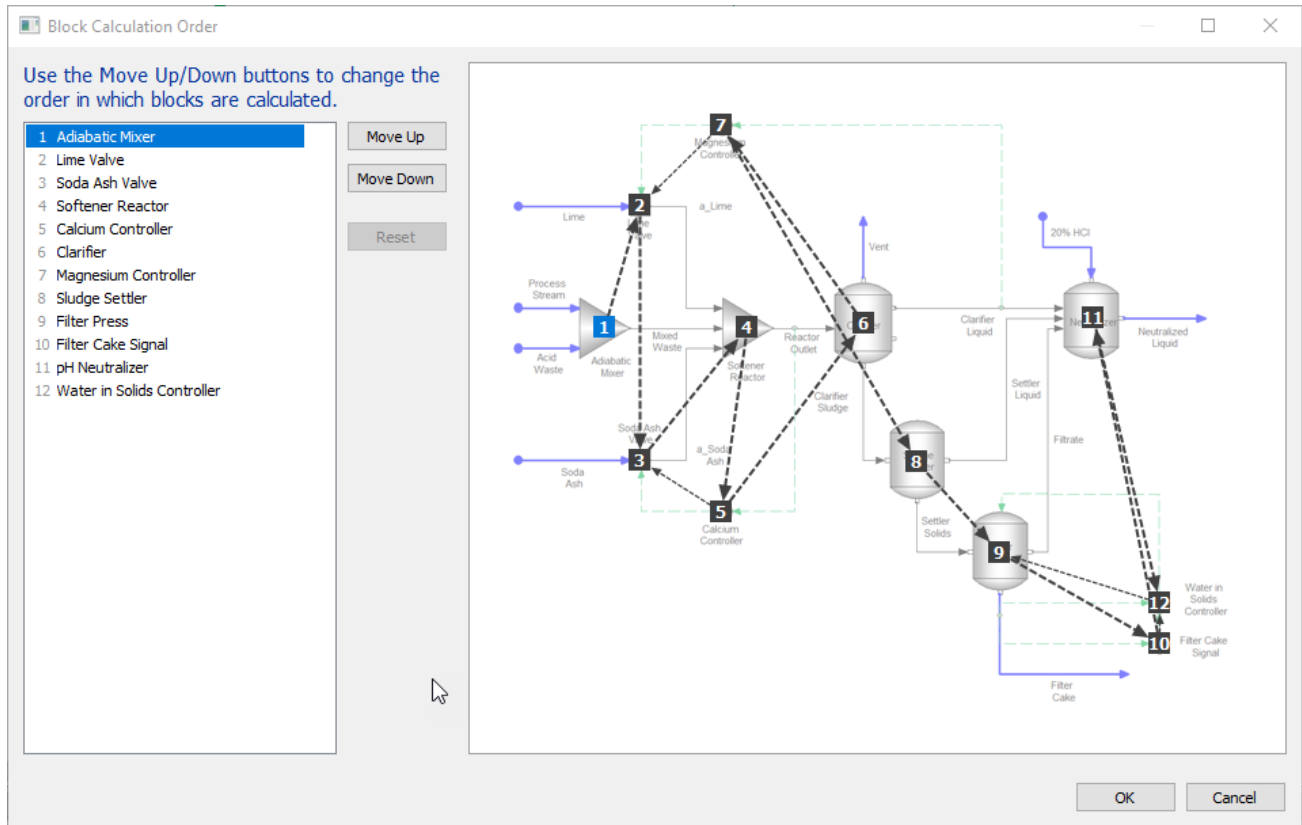
Process	
Definition	General
Process Options	
Optional Properties	>
Recycles	>
Restart Options	>
Molecular Conversion Options	>
Liq-2 Key Component	>
Calculation Aids	>
Block Calculation Order	Edit

- ✓ Locate the **Filter Cake Signal** and ensure that it is before the **Water in solids controller**. If not highlight it and move it up.



- ✓ Open the Block Calculation Order window (an Edit button)

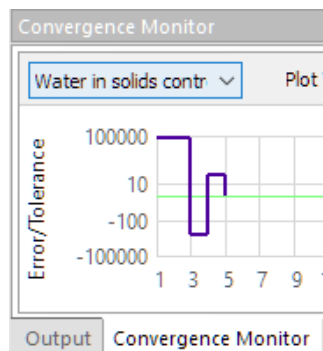
In this case there is not need to move the Filter Cake Signal, since it is first than the Water in solids controller



The Block Calculation Order window. This instructs the software where to start the calculation and in what order the simulation should proceed

- ✓ Press **OK** to leave the window and **Calculate**.
- ✓ Click on the **Convergence Monitor** tab and select the **Water in solids controller**.

The controller took five iterations to converge. The final water content in the filter cake should be 9%.



The Convergence Monitor showing the progress of the Water in solids controller

- ✓ Click on the **Report-1** tab and change the first column to show the Filter Cake
- ✓ Review the Liquid and solid mass in the **Phase Flow** section. If needed change the Mass units to kg/h.

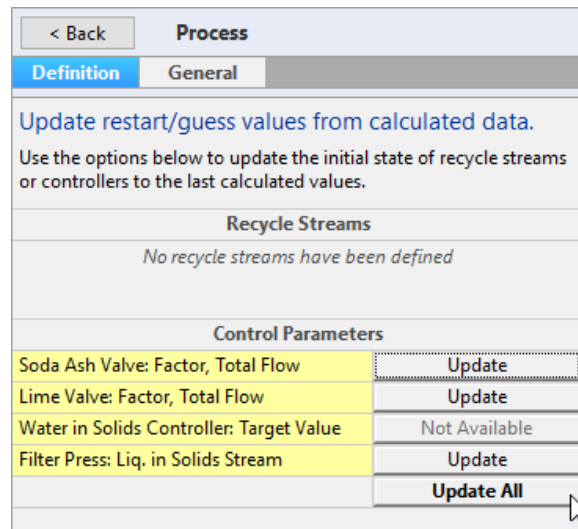
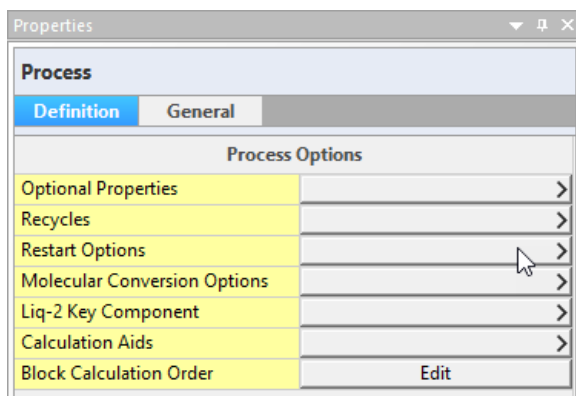
	Filter Cake
	<a href="#">Remove</a>
<b>Phase Flows</b>	
Moles, True - Aqueous (mol/hr)	73.6361
Moles - Solid (mol/hr)	141.493
Moles - Vapor (mol/hr)	0.0
Moles, Apparent - Aqueous (mol/hr)	72.7696
Mass - Aqueous (kg/hr)	1.35044
Mass - Solid (kg/hr)	13.5044
Mass - Vapor (kg/hr)	0.0
Volume - Aqueous (L/hr)	1.32599
Volume - Solid (L/hr)	4.97195
Volume - Vapor (L/hr)	0.0

*The Phase Flow section of the Filter Cake. The Water mass is 1/10<sup>th</sup> the solids mass as designed*

The water content in the filter cake is 9% as designed in the controllers. These controllers took five iterations to converge, and with this additional automation a more robust model is created. What-if scenarios can now be run, in which the stream flow rates or target Ca<sup>+2</sup> and Mg<sup>+2</sup> concentrations are changed, and the filter press will continue to produce a cake with 9 mass% water.

Now that the software converged on the target specification for water, the settings can be updated so that in future calculations the converged case will be the restart point.

- ✓ Click anywhere on the flowsheet (off any block or stream) so that the Flowsheet **Properties** panel is shown.
- ✓ Select the **Restart Options** and then click the **Update All** button.



*Updating all the controllers so that the next time the calculation is run it starts at the converged case*

The settings for filter press controllers are now updated.

The last thing we will do is review the **Filter Press** fractions to see how the controller modified them.

- ✓ Click on the **Filter Press** to access the **Properties** panel.
- ✓ Click on the **Edit** button and review the updated **Liquid splits**.

In order to achieve the 9 wt% water target, the software rerouted 5.4% of the liquid to the filter Cake stream, with the balance exiting the filtrate.

- ✓ Click OK to close the window.
- ✓ **Save** your file. It will be used in the next chapter.

## Summary

This chapter introduces Controllers and Manipulators/Multipliers. Manipulators/Multiplier blocks were added to the lime and soda ash streams to represent flow valves. Each multiplier was controlled by a Feed Back controller that measured the dissolved calcium and magnesium concentrations and adjusted the lime and soda ash flow rates, respectively. Then, the water content in the filter cake was controlled using a Feed Forward controller and a Feedback controller in series.